RESTRICTION ON USE AND DISCLOSURE OF PROPOSAL INFORMATION

Contents

1 Scientific/Technical/Management

1.1 Objectives and Expected Significance

The largest area survey done by the *Spitzer Space Telescope* (Werner et al. 2004) has yet to be fully analyzed. This is not surprising since this survey was not like any other *Spitzer* survey. The *Spitzer* Enhanced Imaging Products (SEIP) catalog (Teplitz et al . 2012) is a survey that is comprised of all the images taken throughout Spitzer's cryogenic mission using the Infrared Array Camera (IRAC; Fazio et al. 2004), covering 3.6, 4.5, 5.8, and 8 microns (IRAC channels 1 through 4), and the Multiband Imager and Photometer for *Spitzer* (MIPS; Rieke et al. 2004), at 24 microns (MIPS channel 1). These cameras were used extensively for both pointed and survey projects. The surveys, of course, covered large sections of sky, but the pointed observations, which inevitably covered more sky than the intended target due to the requirement for mosaicking and the large field of view of both cameras (~5'), created a multitude of mini-surveys resulting in many sources which were never examined because they were not the main science objective for that particular pointing (Figure 1-1).

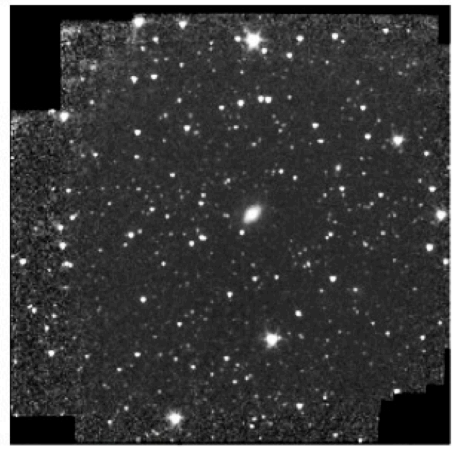

Figure 1-1. A 3.6 μm IRAC mosaic of the galaxy Zw 229-015 (center). Note the sheer number of sources detected in addition to the intended target. The image is ~7.4' on a side.

Large surveys followed by systematic follow-up have frequently led to major breakthroughs in astronomy. In the infrared, for example, ground-based follow-up of the pioneering Air Force Geophysics Laboratory (AFGL) survey led to the identification of the first proto-planetary nebulae, the Egg nebula and GL618 (Ney et al. 1975, Westbrook et al. 1975), while follow-up by Soifer et al. (1984) of the IRAS bright galaxy sample identified the first ultra-luminous infrared galaxy (ULIRG): Arp 220. Spitzer's SEIP catalogue is a large survey and has the potential to yield equally interesting serendipitous discoveries as it contains the key ingredients of those and other surveys that have yielded new objects: large sky coverage, and a significant increase in sensitivity.

In terms of sky coverage, the SEIP, by combining the large number of *Spitzer* pointings into one catalog has created a survey of the sky that covers ~600 square degrees in five photometric bands. If we subtract the area of the standard large *Spitzer* surveys from that final number (e.g. FIDEL, GLIMPSE, GOODS, M31, SAGE, SAGE-SMC, S-COSMOS, SDWFS, SPUDS, SWIRE, and Taurus) that leaves ~150 square degrees that has never been systematically analyzed. That is **three times larger** than the next largest *Spitzer* survey that also covered those five bands: the *Spitzer* Wide-area Infrared Extragalactic (SWIRE) survey (Lonsdale et al 2005).

In terms of sensitivity, the SWIRE survey created a 24 μm (MIPS1) catalog for all sources that had 3.6 and 4.5 μm (IRAC1 and IRAC2) detections resulting in 98,000 sources. The SEIP with the same criteria (with the large surveys subtracted) has 186,000 sources with more sources both at the brighter and fainter end of the distribution (Figure 1-2). This is the result of the wide variety of exposure times used in covering the originally intended targets. In comparing the depths of the two surveys, SIWRE has a number-count turnover at 400 μJy while the SIEP's turnover is a factor of two fainter at 200 μJy. *Hence the SEIP is the largest and deepest 24 μm survey conducted by Spitzer.*

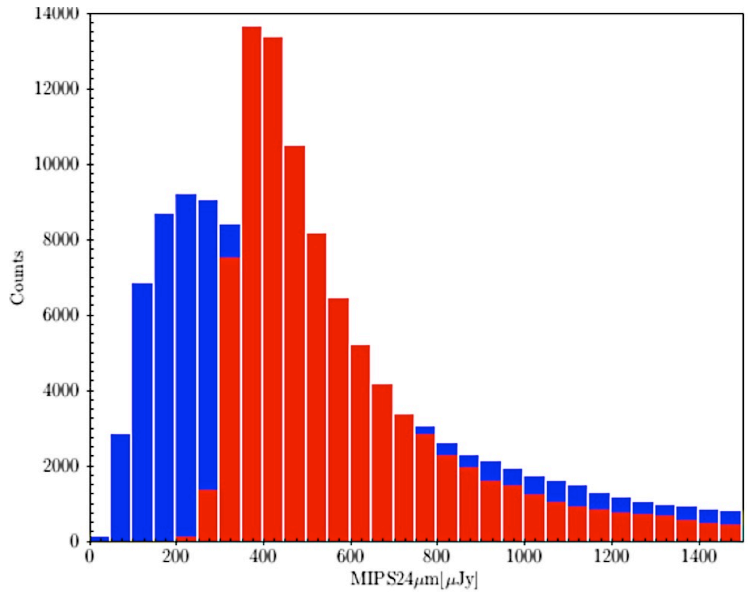

Figure 1-2. Comparison of MIPS 24 μm sources that have IRAC channel 1 and 2 detections from SWIRE (Red, 98,00 total sources) to the SEIP SNR>5 catalog (Blue, 186,000 sources) with standard surveys removed.

One advantage of any large area survey is that the chances for finding rare and unusual sources becomes higher, and so one would think that with similar wavelengths to the SEIP the Wide-Field Infrared Survey Explorer (WISE) (Wright et al. 2010) which imaged the whole sky at 3.4, 4.6, 12, and 22 microns, would have detected all such rare sources. But the WISE catalog has a much lower sensitivity in its long wavelength channel than the SEIP. WISE has a completeness of 5 milli-Jansky at 22 μm, which is a factor of 25 less than the 200 micro-Jansky turn-over for the SEIP at 24 μm.

With such a significant advantage in sensitivity compared to WISE and a significant advantage in area compared to SWIRE, the SEIP archive will allow us to find rare astrophysical sources that are transitional in nature and so evolutionarily very important, but very hard to find.

1.1.1 Objectives

So what types of sources do we expect to find in the SEIP? One of the most productive tools for identifying unusual sources in multi-wavelength surveys is by applying a color selection. In the case of IR observations, an IR excess, where dust absorption of short wavelength light results in re-emitted IR light in excess of the expected stellar light, is a great signal that something unusual is going on. IR excess sources arise from a multitude of interesting astrophysical situations: from dust enshrouded protostars, from evolved stars ejecting dust shells, from main sequence stars that have gone through a cataclysmic event like a collision in their asteroid belt, from star forming galaxies (especially ones which are heavily dust obscured), or from active galactic nuclei (AGN).

Having a large survey over a large part of the sky opens the possibility of detecting critical evolutionary stages of the above noted events, and having a 24 μm catalog that is more sensitive over a larger area than any previous survey opens up the possibility that we will identify sources that no other *Spitzer* 24 μm survey has yet detected.

To show the potential that the SEIP holds for the detection of previously unknown sources we have done a pilot study where we have chosen a small subset of the SEIP to examine for sources with unusual colors.

We extracted from the SEIP all point sources that have a S/N>10 in all IRAC channels and the MIPS 24 μm channel. We removed all the formal surveys, that is any effort where the goal was to try to capture as many sources as possible with the required exposure time. This resulted in a catalog of 57,833 sources. Figure 1-3 shows the distribution of the sources across the sky, differentiating between sources that were removed and those that were kept.

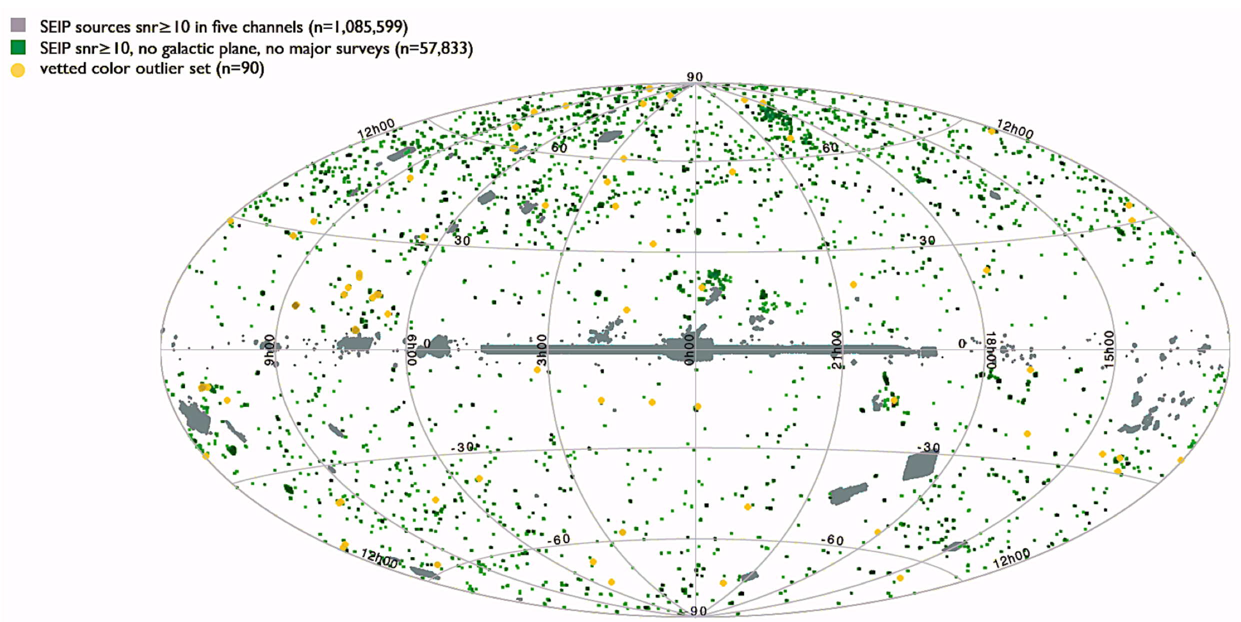

Figure 1-3. SEIP sources selected based on S/N>10 in all IRAC channels and the MIPS 24 μm channel. The gray regions are surveys that have been removed from the pilot survey. The yellow sources are the vetted IR excess sources from the color-color diagram in fig 1-4.

We plotted all the sources on an I1-I2 vs. I4-M1 color-color diagram (figure 1-4) to see which ones had an unusual color. This is not as trivial as it may sound since the SEIP is not an actual source matched catalog as explained in the SEIP Explanatory Supplement: “2.1.5 Band-merged multi-wavelength catalogs are associations, not identified counterparts” where sources at 24 μm that are within 3” of an I1 or I2 source are included in the catalog as an association. This requires individual visual inspection of all sources that are deemed to be of interest based on their color.

The resulting color-color diagram is heavily biased towards sources having an IR excess in the MIPS band due to the requirement of having a high S/N in our M1 selection.

We chose all outliers in the color-color diagram that were significantly displaced from the main locus of points. This totaled 112 sources. Of these, there were 22 that did not pass visual inspection where either the M1 source was shifted with respect to the IRAC detected source or there was a cosmetic issue at one of the bands. Of the 90 remaining sources, another 22 were previously identified sources, meaning there was a catalog reference for those sources in either the NASA Extragalactic Database or the SIMBAD database, leaving 68 sources which had no reference in the literature. Of those 22 previously cataloged sources, 7 had no reference to unusual IR properties. So combining those 7 with the 68 previously undiscovered sources gives 75 new sources which have extreme IR colors. Most have an IR excess either at I1-I2 or I4-M1 or both, but some have somewhat blue I1-I2 colors as well.

After having identified these 90 sources we wanted to do a preliminary identification of them so we have plotted their magnitude distribution in figure 1-5. Comparing their magnitude distribution to the overall

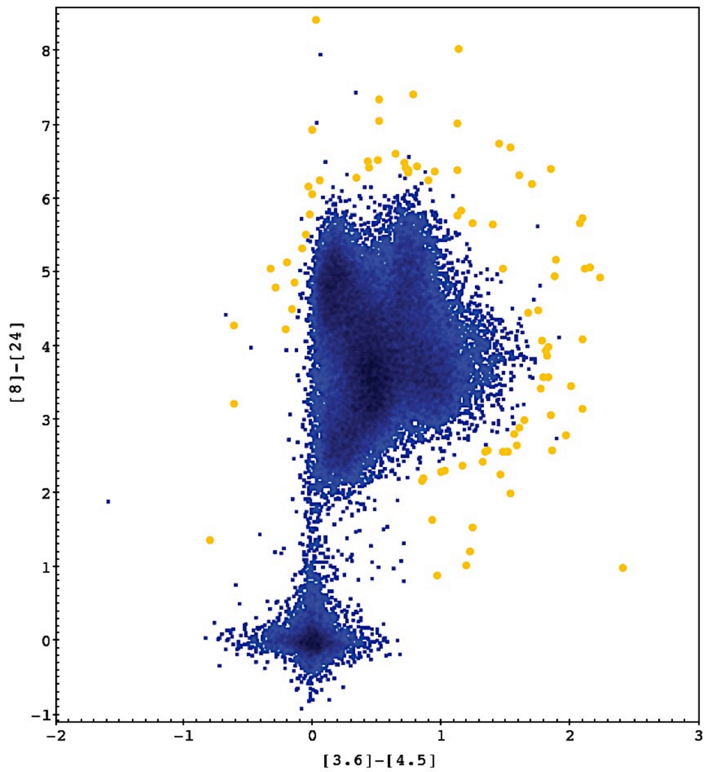

Figure 1-4. Color-color diagram of all SEIP sources with S/N>10 (Blue). Of the 122 sources displaced from the main locus, there are 90 (Yellow) which have been individually examined to show that they are matched at all wavelengths and so the excess is not an artifact of the larger MIPS beam or other cosmetic defect.

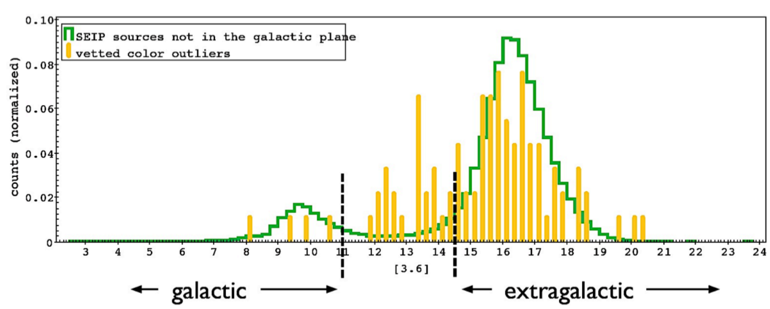

Figure 1-5. Normalized distribution of color outliers (yellow) as compared to the overall distribution of sources in the SEIP (green) that do no lie near the Galactic plane (|b|>5). Sources may be roughly classified by magnitude as galactic (bright, and so presumably nearby) or extragalactic (faint, and so presumably far away), with an ambiguous group lying between the two regions.

distribution of sources in the SEIP indicates that the majority of sources are likely extragalactic, though there are a fair number of sources that have an ambiguous classification.

So what potential science might be gained from these previously unknown sources? By having a large and deep survey we are targeting phenomena that have a short lifetime like the previously noted proto-planetary nebulae that have a lifetime of only about 10,000 years. As an illustrative example of this we would like to note how the discovery of transitional/short lived objects can give new scientific insights into the phenomena of debris disks and hyper/ultra-luminous Infrared galaxies.

Debris disks: For main sequence stars that have formed rocky and/or icy planetesimals within their stellar systems, the collision and/or evaporation of those objects can create circumstellar debris disks which then generate an IR excess. The warm dust (in excess of ~150 K) generated by those processes (showing an excess at 24 μm) is thought to be a signpost of planets at or near the terrestrial-planet zone, and hence analogous to our solar system's own asteroid belt. But the dynamical timescales for clearing out that debris is small and hence makes such sources a relatively rare phenomenon. To date ~370 warm debris disks have been identified based on targeted surveys (Chen et al. 2005a,b; Su et al. 2006; Beichman et al. 2006; Trilling et al. 2008; Carpenter et al. 2009; Plavchan et al. 2009, Morales et al, 2011) and so the addition of a potentially large sample of warm debris disks from the SEIP can make a significant contribution to our understanding of the evolution of extra-solar planetary systems and, in particular, the parent stars (spectral type, age, and metallicity) that might be most conducive to the evolution of planets in the terrestrial-planet zone.

Hyper and Ultraluminous Infrared Galaxies (HyLIRG's and ULIRG's): Galactic mergers lead to some of the most spectacular IR excess sources in the form of ULIRGs which heat dust through a combination of AGN activity and large scale and rapid star formation (e.g. Sanders & Mirabel 1996). These sources represent an important phase in the buildup of massive galaxy bulges and in the growth of their central supermassive black hole. The connection between how the mass of the bulges is correlated with the mass of the central black hole as initially shown by Ferrarese & Merritt (2000) and Gebhardt et al. (2000) is likely intimately connected to this very active phase of the galaxy's evolution.

In tracing the important milestones of galaxy evolution, Eisenhardt et al. (2012) used WISE data to find hyper luminous IR galaxies which have luminosities greater than 10^{13} L_{Sun}. These sources are powered primarily by AGN activity and are likely the relatively short lived, early stages of merging galaxies where the gravitational disturbance has caused a massive amount of gas to flow onto the central supermassive black hole. Only about 1000 such sources have been identified in the WISE all-sky survey. Wu et al. (2012) have shown that a selection using a weak near-IR emission in WISE bands 1 and 2 (3.4 and 4.6 μm) combined with the WISE 22 μm filter is an effective way of identifying these sources.

The less luminous counterparts of the excess sources were identified using their optical and 24 μm signature by Dey et al. (2008) in the 8.5 square degree *Spitzer* Deep Wide-Field Survey (SDWFS) and dubbed dust obscured galaxies (DOG's). Unlike other ULIRG's whose dust temperature is primarily set by large-scale star formation, DOG's have emission from dust that is at a higher temperature and so likely have a significant AGN component. What can be seen in Figure 1-6 is that between the HyLIRG's and the DOG's there is a gap in known sources to trace the potential evolutionary path from the rare HyLIRG phase (also referred to as the Hot DOG phase) to the more common DOG phase. What is necessary is a survey that has greater sensitivity than WISE but greater areal coverage than SDWFS which is precisely what the SEIP offers.

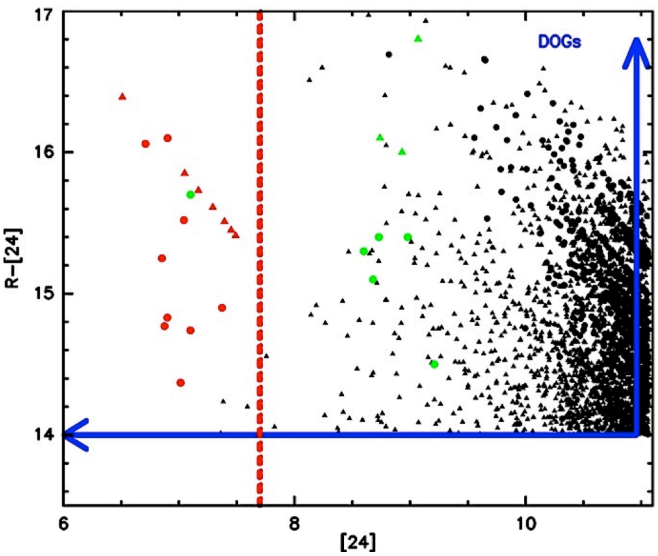

Figure 1-6. HyLIRG's (red) compared to DOG's (Black) from SDWFS (Dey et al. 2008, black). Circles represent targets with *R*-band detections and triangles denote targets with *R*-band upper limits. Blue lines and arrows demonstrate the DOG selection criteria by Dey et al. (2008), and the red dashed line marks the lower limit of WISE 22 μm flux density. Green sources are those that have been followed up at sub-millimeter wavelengths. Note the gap on the x-axis between [24] ~ 7.5 (limit of the WISE detected HyLIRG's) and [24] ~ 9 where the SDWFS detected DOG's start rising in numbers. The SEIP counts turnover at [24] = 11.4. Figure from Wu et al. (2012)

1.1.2 Expected Significance

There are two aspects to the scientific significance of the final result. One is a direct scientific impact and the other is more indirect and is from potential changes in how future observations will be conducted.

The more direct scientific impact, of course, comes from covering a large area of sky with five filters to significant depths, but most importantly at 24 μm, for which the SEIP is the largest and deepest survey. Such high sensitivity at 24 μm over a large area allows us to discover sources which have warm dust emitting phases with very short lifetimes. Already in our small pilot survey we have detected 75 previously unknown extreme IR excess sources.

The indirect scientific impact of this project is on how future observations may be bundled to provide more scientific return. The fact that the SEIP is a catalog constructed from pointed observations, each yielding numerous sources that are not preselected, is what sets it apart from other *Spitzer* surveys. *The SEIP's wealth of unexplored additional sources has great significance for target selection for future observations by any telescope, but most importantly the James Webb Space Telescope (JWST).* Any future target list for JWST will be heavily influenced by the vast number of sources that were initially studied by *Spitzer*. As is the case with almost all observations, an initial set of observations determine whether follow-up is warranted and so sources already studied by *Spitzer* will be high on the list of sources likely to be approved for observation by JWST. Hence by having a catalog of sources derived from the SEIP that are near the originally targeted *Spitzer* sources that will be followed up by JWST increases the potential return for JWST's pointed observations. In terms of imaging this can be accomplished by making sure that a mosaic also contains the interesting ancillary SEIP source, or in terms of spectroscopy where a simple rotation of the slit or selection of appropriate pixels in the microshutter array will include the additional SEIP target. This way, by knowing if there are other interesting targets close to the targets likely to be proposed for JWST, a proposer can instantly increase the scientific return of their observation. So this survey can provide both a set of new primary targets for JWST to follow-up *and* a secondary set of targets which happen to be close to the primary target.

1.2 Technical Approach and Methodology

1.2.1 Selecting sources

Our approach will be an extension of our pilot survey to lower S/N. We will begin our study considering all objects in the SEIP catalog that have I1, I2, I4 and M1 fluxes that have a SNR > 5. We will avoid the other *Spitzer* surveys as they have already been mined for IR excess sources. This gives a total source count of 186,000 sources which is twice as large as the next largest *Spitzer* survey. Also there is a significant amount of cirrus close to the Galactic plane so, in addition to avoiding the GLIMPSE survey, we set a limit of |b| > 5 to minimize the confusion at 24 μm wavelengths introduced by cirrus.

The first step in the process of identifying IR excess objects is to generate color-color plots. Figure 1-4 shows an example of this approach. Sources that have stellar spectral energy distributions (SED's), whether they are individual stars or elliptical galaxies with a composite of various stellar spectra, are expected to have a color of around zero magnitude. Sources with an excess of emission over stellar emission rise up and to the right in the figure.

What is evident from our pilot survey is that there are a lot of sources that have an IR excess. Now this is in part due to the selection of high S/N M1 sources. Sources that have SED's following the Raleigh-Jeans law are getting fainter towards longer wavelengths and so making a source list that insists on a high S/N detection at 24 μm biases the sample in favor of IR excess objects.

There are also many outliers both in the blue and red I1-I2 regions though we were cautious and threw out 22 sources out of the 112 original outliers to be sure that we were not chasing instrumental artifacts, in particular the lower resolution of the MIPS camera vs. the IRAC camera.

This is well demonstrated in Figure 1-7. It is an image of one of the outlier IR excess sources from Figure 1-4, but when the images for the source are examined, it becomes evident that the region is very crowded and the lower resolution M1 image may be combining the flux of additional sources into one data point and so possibly giving a false indication of an excess.

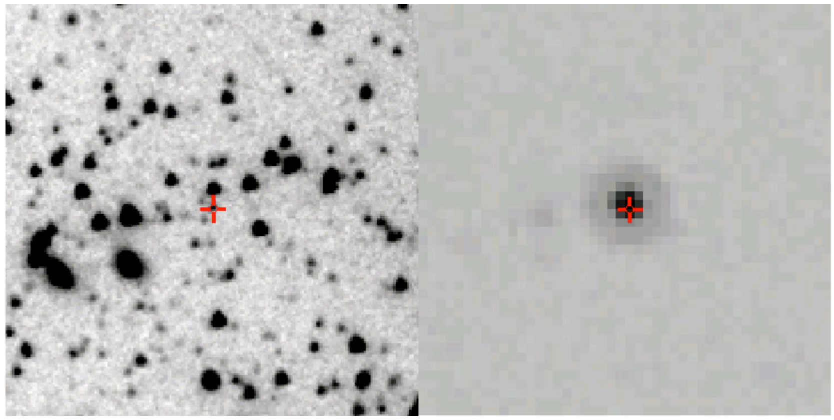

Figure 1-7. Source, marked by red cross, selected based on IR excess. The image on the left is IRAC1 at 3.6 μm and the image on the right is MIPS1 at 24 μm. Note the crowded field and that many of the resolved sources at 3.6 μm are perhaps being lumped into one source at 24μm possibly giving a false IR excess where the red identifying cross in the MIPS image is offset below the center of the imaged source. Images are both North is up and East is to the left and at a scale of 1.8'x1.8'

This is where the other three IRAC channels become very useful. Since they are all at the same resolution, 1.2 arcseconds per pixel, if there is a rising trend from 4.5 to 8.0 μm which then continues out to 24 μm, then the IR excess is likely real and associated with the identified IR excess source. But if the MIPS1 channel is the only channel showing an excess or if the source is not detected in IRAC channels 3 and 4, then it is much less likely that the source has a real IR excess.

This issue then highlights one of the key challenges for this proposed effort. Although many potential 24 μm IR excess sources can be automatically vetted based on a rising SED at the shorter IRAC channels, it is vital to do an individual visual check of sources that show an excess only at 24 μm. If there are no other contaminating sources within the MIPS beam, then the excess is likely real. For the most unusual sources, a visual inspection will be required regardless of the trend in the IRAC channels as often some contamination (e.g. flux from a nearby bright star) is responsible for the odd SED.

1.2.2 Categorizing sources

Once the IR excess sources have been identified and have been shown to be reliable, the next step is to try to categorize them. Of course spectroscopy will always be the final arbiter of source type, but we can use photometric and other techniques to make preliminary assignments to five main source types: Debris Disk, Young Stellar Object (YSO), Evolved star (e.g. AGB), various luminous infrared galaxies (LIRG's), and AGN's.

A color-magnitude diagram will be the first step in this determination. Broadly speaking, the majority of the fainter sources will be likely extragalactic while the majority of the brighter sources will be Galactic. After this separation, a location dependent identification will be applied where sources significantly above the Galactic plane will likely be extragalactic.

Then we will use data from the Two Micron All-Sky Survey (2MASS) (Skrutskie et al. 1997) to better identify the source types, in particular helping to identify AGB stars since they tend to have a fairly well defined region in near-IR color-magnitude space (e.g. Jung et al. 2012). Also if a stellar spectroscopic classification already exists in SIMBAD, it will be of great help in identifying evolved stars.

Shorter wavelength IRAC data (Channels 1 and 2) tend to separate a large percentage of AGN and star forming galaxies very well (e.g. Stern et al 2005, Gorjian et al. 2008). So that process will be used to identify the AGN and starbursts in the IR excess sample.

Finally, we will use the Palomar Observatory Sky Survey (POSS) which has better spatial resolution than the SEIP to help identify galaxies based on their extended appearance.

1.2.3 Modeling the sources

Stars with IR excess lend themselves to modeling using a single or double blackbody spectrum for the IR emission from dust (Figure 1-8). Co-I Morales has developed software that can estimate various parameters of the IR excess system such as dust temperature(s), IR excess ratio, estimated dust masses and minimum locations.

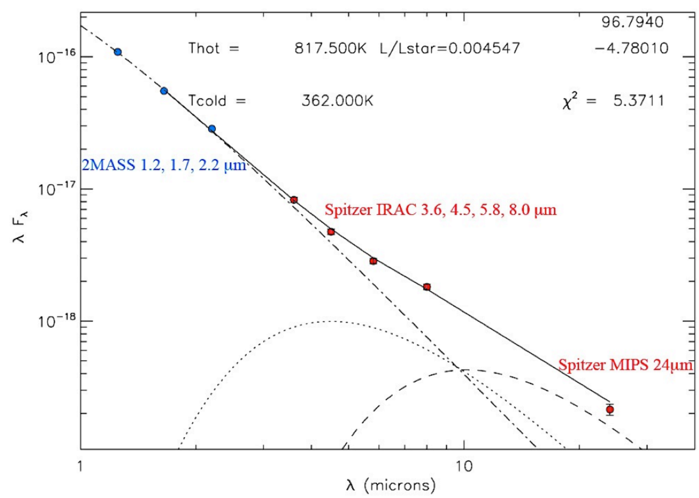

Figure 1-8. SED fit (solid line) and modeled dust temperatures using data from 2MASS and *Spitzer* for the star ID 18566 in the cluster NGC 2232. Note that without the combination of these two datasets it would be impossible to pin down the photosphere (dot-dashed line) and hence make a proper assessment of the IR excess and the contribution of the hot dust (dotted curve) and cold dust (dashed curve). Figure from Currie, Plavchan and Kenyon (2008).

To achieve the identification and characterization of circumstellar excesses, it is necessary to have a good measure of the expected photospheric contribution. This requires two approaches: 1.) Fitting photospheric models (Kurucz and/or NextGen) to the stellar photometry in the SEIP with the addition of J, H and K_s bands from 2MASS; and 2.) using the 2MASS K_s and the IRAC1 channel to extrapolate the photospheric emission. Photospheric model fitting should have a significant advantage over magnitude and color cuts because it uses more data, but in some cases with MIPS1-only excesses, this approach alone does not give good results (Trilling et al. 2008). We will develop a composite approach to extrapolating stellar photospheres, providing a homogeneous set of criteria for the identification of infrared excesses. With accurate averaging of photospheric colors derived from large numbers of stars in the SEIP, we will compare with stellar photospheric Kurucz and/or NextGen models and determine the intrinsic stellar behavior at the SEIP bands (per stellar spectral type). We will then combine these with the ancillary shorter-wavelength data (2MASS), resulting in a "self-calibration" technique, required in determining the intrinsic stellar contribution per stellar spectral type, for the enhancement of candidate detection. ∼350 warm debris systems characterized with Spitzer spectroscopy (Morales et al. 2011; Chen et al. 2014) will serve as guides. While the debris disks from Morales et al. (2011) represent more typical warm excesses, the colors of β Pic and ε Eri will help us in identifying debris disks with particularly large excesses.

Transitional Disks are YSOs (young stellar objects) with inner holes in their depleted primordial disks, and have colors and SEDs similar to debris disks. The location and kinematics of all debris disk candidates will be examined for potential association with known star forming regions and young clusters. It is likely that groups of previously unknown IR excess stars may establish new kinematic associations or moving groups

1.3 Perceived Impact to State of Knowledge

Here we will use our two illustrative cases. For debris disks and HyLIRG's, it is necessary to use large area surveys with high sensitivity to find enough sources to statistically address their evolution. For both those cases, 24 μm observations are vital and the SEIP provides high sensitivity and a large area at that wavelength as well as the other *Spitzer* wavelengths, all of which are necessary to help identify the IR excess sources.

At the moment there are about 350 known warm dust debris disks. Patel et al. (2014) showed using WISE data that, within 75 pc, about 2% of stars have warm dust IR excesses. For our S/N >5 sample of 186,000 sources, even if only 15% of our sources are Galactic (extrapolating based on our pilot study), then that 2% results in over 500 new sources! These new sources make for a significant increase beyond the current sample and potentially contain many rare/transitional objects.

In terms of galaxy evolution, the picture that exists now is that a galaxy evolves by going through an extreme star formation phase that is then quenched by an AGN phase (e.g., Hopkins et al. 2008 and references therein). The HyLIRG's and DOG's both have great amounts of star formation but their AGN's are the dominant energy source and so addressing how long that AGN phase lasts becomes very important. Are HyLIRG's a separate and rare population or are they the hotter portion of the DOG population? If HyLIRG's are simply Hot DOG's then there should be a nice continuum in numbers between the two populations in their 24 μm based color-magnitude diagram. If HyLIRG's are a separate and rare population, then we should not find a significant number of sources populating the gap between them and the DOG populations. In this latter case it becomes unlikely that the HyLIRG phase is the star formation quenching phase in the evolution of a galaxy. Either way, this improves the state of knowledge about galaxy evolution and whether all galaxies must go through a HyLIRG phase to quench their star formation.

1.4 Relevance to Element Programs and Objectives in the NRA

The proposed work falls squarely within the Archival Research aspect of the Research & Analysis program element of the NASA's SMD Science Plan for 2007-2016. We will exploit the archives of two NASA IR missions/programs (*Spitzer*, 2MASS) to address vital but rare evolutionary phases of astrophysical phenomena. The S2D2 project offers an opportunity to pursue NASA strategic objective 2.4: "Discover how the universe works, explore how it began and evolved, and search for Earth-like planets." In addition, S2D2 addresses three of the highest-priority scientific goals recommended in the "New Worlds, New Horizons" decadal survey: 1. "Giving Meaning to the Data: Cyber-Discovery" where we will be using multiple archives to make discoveries. 2. "The Origin of Stars and Planets" where we will be looking at the critical disk phase of star formation when planets are forming. 3. "The Origin of Galaxies and Large-Scale Structure" where we will be identifying a large number of sources going through the ULIRG and AGN phases which are thought to be key phases of galaxy evolution.

1.5 Work Plan

1.5.1 Key Milestones

Year One: We will identify the IR excess sources and assemble a database with a reliability rating for each source. For sources that have lower reliability (overcrowded region, MIPS1 only IR excess) then we will flag them for visual follow-up.

Once the catalog is deemed reliable, then we will separate the IR excess sources into the various potential IR excess categories noted earlier.

Year Two: Model the stellar sources debris disks to get their dust characteristics. Publish the catalog for all the IR excess sources with our initial identifications of which types of objects they are likely to be and include the model determined parameters for the debris disks.

1.5.2 Management Structure

Dr. Gorjian of JPL is the PI of this investigation. He is responsible for the quality and direction of the proposed research and the proper use of all awarded funds. He is also responsible for all technical, management, and budget issues and is the final authority for this task. The Co-I will report to and take direction from the PI and will provide all the management data needed to ensure that the he can effectively manage the entire task.

1.5.3 Contributions of Principal Investigator and Key Personnel

Principal Investigator

Dr. Gorjian of JPL of will lead the effort and will be the main person coordinating the work on the determination of the IR excess sources in the catalog.

Key Personnel

Dr. Morales of JPL, Co-I, will lead the modeling effort and will aid in the vetting of the sources.

1.5.4 Collaborators and Consultants

Dr. Geoffrey Bryden of JPL, Collaborator, will aid in the modeling effort of the IR excess sources.

1.5.5 Risk Management

No risk management is necessary for this project.

1.6 Foreign Participation

N/A

1.7 Data Sharing

The proposed project will generate a catalog of infrared excess sources (RA, Dec, IRAC, and MIPS fluxes) and this data will be shared at the time of publication via supplementary material associated with publications.

2 References and Citations

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3 Biographical Sketch

3.1 Principal Investigator

VAROUJAN GORJIAN
RESEARCH SCIENTIST
JPL, MS 169-506, 4800 Oak Grove Dr., Pasadena, Ca, 91109, vg@jpl.nasa.gov, 818-354-2068

RELEVANT EXPERIENCE

Dr. Gorjian has extensive experience in dealing with large surveys. His thesis was looking for the Cosmic Infrared Background in a two degree by two degree region of sky and cataloging and subtracting all foreground sources. He has also been a Co-I of several *Spitzer* large-area surveys including the *Spitzer* Deep Wide-Field Survey (SDWFS), Surveying the Agents of A Galaxy's Evolution (SAGE), and The *Spitzer* Kepler Survey (SpiKeS).

Education

Ph.D., Astronomy & Astrophysics, UCLA (1998)
M.S., Astronomy & Astrophysics, UCLA (1994)
B.S., Astrophysics, California Institute of Technology, (1992)

Research Interests

- Study of Active Galactic Nuclei (AGN) with emphasis on determining their intrinsic luminosity and their fueling mechanism.
- Infrared and Radio imaging of young star forming regions, which may be the sites of globular clusters in formation.
- Determining the Cosmic Infrared Background (CIRB) in the near infrared to help constrain the cosmic star formation history.

Professional Experience

Jet Propulsion Laboratory (2000 – present)
  Research Scientist (2004 - present)
  Scientist (2000 – 2004)
Herschel Project Science Office Scientist (2002–2004)
Spitzer Project Science Office Scientist (2000-present)
Spitzer Science Center (June 2006 – present)
  Member of Education and Public Outreach team
National Research Council Resident Research Associate, JPL (1998–2000)

Recent Projects

- Ongoing *Spitzer* imaging and spectroscopy of X-ray selected Seyfert galaxies.
- Comparison of IRAC Shallow Survey data with *Chandra X-Ray Observatory* data
- Member of *Spitzer* Legacy teams imaging the LMC and SMC from 3.6 to 160 microns
- Provide training to teachers across the US in using *Spitzer* data in the classroom
- Ground based mid-IR high-resolution imaging & spectroscopy of nearby dwarf starbursts
- *Spitzer* AGN variability monitoring of AGN in the *Kepler* Space Telescope and SDSS fields
- Headed *Spitzer* team that imaged the nearby, metal poor, star forming region Henize 206 in the Large Magellanic Cloud, resulting in a *Spitzer* Science Center press release.
- Used the JPL mid-IR camera on the Palomar 200" to compile the largest, uniform, 10μm imaging sample of Seyfert nuclei to date with continuing variability monitoring

Publications Relevant to this Proposal

Gorjian, V.; Brodwin, M.; Kochanek, C. S.; Murray, S.; Stern, D.; Brand, K.; Eisenhardt, P. R.; Ashby, M. L. N.; Barmby, P.; Brown, M. J. I.; and 9 coauthors *The Mid-Infrared Properties of X-ray Sources*, 2008ApJ...679.1040

Gorjian, V.;Wright, E. L.;Chary, R. R. *Tentative Detection of the Cosmic Infrared Background at 2.2 and 3.5 Microns Using Ground-based and Space-based Observations*, 2000ApJ...536..550

Ashby, M. L. N.; Stern, D.; Brodwin, M.; Griffith, R.; Eisenhardt, P.; Kozłowski, S.; Kochanek, C. S.;Bock, J. J.;Borys, C.;Brand, K.;Gorjian,V;and 22 other authors *The Spitzer Deep, Wide-field Survey*, 2009ApJ...701..428

Other Recent Publications

Mason, R. E.; Levenson, N. A.; Shi, Y.; Packham, C.; Gorjian, V.; Cleary, K.; Rhee, J.; Werner, M. *The Origin of the Silicate Emission Features in the Seyfert 2 Galaxy NGC 2110*, 2009ApJ...693L.136

Krick, J. E.; Surace, J. A.; Thompson, D.; Ashby, M. L. N.; Hora, J. L.; Gorjian, V.; Yan, L. Galaxy *Clusters in the IRAC Dark Field. I. Growth of the Red Sequence*, 2008ApJ...686..918

Bernard, Jean-Philippe; Reach, William T.; Paradis, Deborah; Meixner, Margaret; Paladini, Roberta; Kawamura, Akiko; Onishi, Toshikazu; Vijh, Uma; Gordon, Karl; Indebetouw, Rey; Gorjian, V. and 39 coauthors *Spitzer Survey of the Large Magellanic Cloud, Surveying the Agents of a Galaxy's Evolution (sage). IV. Dust Properties in the Interstellar Medium*, 2008AJ....136..919

Whitney, B. A.; Sewilo, M.; Indebetouw, R.; Robitaille, T. P.; Meixner, M.; Gordon, K.; Meade, M. R.; Babler, B. L.; Harris, J.; Hora, J. L.; Gorjian, V. and 45 coauthors *Spitzer Sage Survey of the Large Magellanic Cloud. III. Star Formation and ~1000 New Candidate Young Stellar Objects*, 2008AJ....136...18W

Hickox, R. C.; Jones, C.; Forman, W. R.; Murray, S. S.; Brodwin, M.; Brown, M. J. I.; Eisenhardt, P. R.; Stern, D.; Kochanek, C. S.; Eisenstein, D.; and 6 coauthors, *A Large Population of Mid-Infrared-selected, Obscured Active Galaxies in the Boötes Field,* 2007ApJ...671.1365

Gorjian, V.; Cleary, K.; Werner, M. W.; Lawrence, C. R., *A Relation between the Mid-Infrared [Ne V] 14.3 μm and [Ne III] 15.6 μm Lines in Active Galactic Nuclei,* 2007ApJ...655L..73G

Shi, Y.; Rieke, G. H.; Hines, D. C.; Gorjian, V.; Werner, M. W.; Cleary, K.; Low, F. J.; Smith, P. S.; Bouwman, J., *9.7 μm Silicate Features in Active Galactic Nuclei: New Insights into Unification Models*, 2006ApJ...653..

3.2 Co-Investigator(s)

Farisa Y. Morales

Jet Propulsion Laboratory, Caltech
4800 Oak Grove Drive, MS 169-506
Pasadena, CA 91109

Phone: (818) 354-1940
Fax: (818) 354-8895
Email: `Farisa@jpl.nasa.gov`

RESEARCH INTERESTS

- **Debris Disk Incidence and Characterization:** To assess the frequency of planetary system formation by investigating circumstellar planetary debris disks of dust, characterized by infrared excesses over photospheric levels, and by studying their spectral energy distributions (SEDs) to investigate their dust spatial distribution, chemical composition, and evolution.
- **Debris Disk Modeling:** To advance our understanding of disk architecture and grain properties, by modeling the SEDs of circumstellar dust around main sequence stars using spectroscopic and photometric data.
- **High-Contrast Imaging:** To search for dust-shepherding exoplanets using the Adaptive Optics systems at Keck II Observatory in HI, and Palomar Observatory in CA

EDUCATION

Ph.D. in Physics, August 2011, University of Southern California (USC), Los Angeles, CA
MS. in Physics, December 2005, California State University, Northridge (CSUN), Northridge, CA
BS. in Astrophysics, June 2003, University of California, Los Angeles (UCLA), Los Angeles, CA

PROFESSIONAL EXPERIENCE

Apr 2006 – present	Staff Scientist - Jet Propulsion Laboratory (JPL)
Aug 2011 – present	Adjunct Faculty - California State University, Northridge
Aug 2007 – Jun 2011	Teaching Assistant, Department of Physics & Astronomy at USC
Feb 2007 – May 2011	Adjunct Instructor at Los Angles Community College District
Nov 2001 – Mar 2006	Staff Scientist (Academic Part-Timer) - Spitzer Space Telescope

AWARDS

JPL Mariner Award (Aug 2013)
American Astronomical Society (AAS) Chambliss Award (January 2011)
La Opinion Newspaper 'Mujeres Destacadas' Award (March 2011)
The Adrian Herzog Outstanding Graduate Student Award (June 2004)

RECENT PUBLICATIONS

- "Herschel-resolved Outer Belts of Two-belt Debris Disks Around A-type Stars: HD 70313, HD 71722, HD 159492, and F-type: HD 104860" by Morales, F. Y., Bryden, G., Werner, M. W., & Stapelfeldt, K., 2013, ApJ, 776, 111
- "WISE Detections of Dust in the Habitable Zones of Planet-bearing Stars" by Morales, F. Y., Padgett, D. L., Bryden, G., Werner, M. W., & Furlan, E., 2012, ApJ, 757, 7
- "Common Warm Dust Temperatures Around Main-Sequence Stars" by Morales, F. Y., Rieke, G. H., Werner, M. W., Bryden, G., Stapelfeldt, K. R., & Su, K. Y. L., 2011, ApJ, 730, L29
- "Spitzer Mid-IR Spectra of Dust Debris Around A and late B Type Stars: Asteroid Belt Analogs and Power-Law Dust Distributions" by Morales, F. Y., Werner, M. W., Bryden, G., Plavchan, P., Stapelfeldt, K. R., Rieke, G. H., Su, K. Y. L., Beichman, C. A., Chen, C. H., Grogan K., Kenyon, S. J., Moro-Martin, A., & Wolf, S., 2009, ApJ, 699, 1067

4 Current and Pending Support

4.1 Personnel and Work Effort

Name	Organization	Role	Work Commitment			
			Year 1	Year 2	Year 3	Year 4
Dr. Varoujan Gorjian	JPL	Principal Investigator	.27	.27	0	0
Dr. Farisa Morales	JPL	Co-Investigator	.27	.27	0	0

4.2 Current Awards

PI - Varoujan Gorjian

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/Total Budget	Commitment (Person-Months per Year)
M. Werner	GO11 Werner-Mik/SIRTF Science Ctr & Outreach	SPITZER SPACE TELESCOPE (SST)/NASA/Suzanne Dodd (JPL PROJECT MGR) / 818-354-1128 / srdodd@jpl.nasa.gov	3/2015 – 9/2018	6
L. Storrie-Lombardi	GO10 Gorjian-Var/SIRTF Science Ctr & Outreach	SPITZER SPACE TELESCOPE (SST)/NASA/Suzanne Dodd (JPL PROJECT MGR) / 818-354-1128 / srdodd@jpl.nasa.gov	1/2013 – 9/2016	1.2
L. Storrie-Lombardi	GO11 Gorjian-Var/SIRTF Science Ctr & Outreach	SPITZER SPACE TELESCOPE (SST)/NASA/Suzanne Dodd (JPL PROJECT MGR) / 818-354-1128 / srdodd@jpl.nasa.gov	3/2015 – 9/2018	2.4
S. Levin	Space Astronomy Research Analysis	Goldstone Apple Valley Radio Telescope (GAVRT)/NASA/ Steve Levin (JPL)/ 818-354-1917/levin@jpl.nasa.gov	10/2011 - 9/2015	1.2
L. Rebull	Teachers Arch Res Pro/Extra Solar Zodiacal Mtl	SCIENCE MISSION DIRECTORATE (SMD), LTSA, ADAP/NASA/ DOUGLAS HUDGINS (NASA HQ)/douglas.m.hudgins@nasa.gov	1/2014 – 1/2015	3

Co-I Farisa Morales

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Point of Contact telephone and email	Period of Performance/ Total Budget	Commitment (Person-months per Year)
Dr. Michael Werner	Science Office/SIRTF Science Ctr & Outreach	Spitzer Space Telescope (SST)/NASA/Suzanne Dodd (JPL Project Mgr) (818) 354-1128 srdodd@jpl.nasa.gov	10/2003 - 09/2016	6.0
Dr. Farisa Morales	Do Debris Disks With Warm Dust Have A Cold Origin?-- Searching For The Outer Planetesimal Belts	Herschel OT2 Grant/ Kirsten Badaracco-Arnold (818) 393-7784 kirsten.m.badaracco @jpl.nasa.gov	01/01/15 - 12/31/15 40.0K	1.0
Dr. Farisa Morales	Constraining the Long Wavelength Emission of Two-Belt Debris Disks	Herschel OT2 Grant/ Kirsten Badaracco-Arnold (818) 393-7784 kirsten.m.badaracco @jpl.nasa.gov	01/01/16 - 12/31/16 25.0K	1.0
Dr. Farisa Morales	Follow up of Candidate Exoplanets Follow-Up and Survey of Stars with Two-Belt Debris Disks from Recent *Spitzer+ Herschel* and WISE Samples	Keck PI Data Award/ Joseph Stuesser (626) 395-1851 joseph.j.stuesser @jpl.nasa.gov	01/01/15 - 12/31/16 30.0K	1.0
Dr. Geoffrey Bryden	Herschel Heritage Debris Disks (H2D2)	NASA Astrophysics Data Analysis Program NNH14ZDA001N-ADAP Douglas M. Hudgins (202) 358-0988 Douglas.M.Hudgins @nasa.gov	FY2015 - FY2017 380.0K	4.0

4.3 Pending Awards

PI: Gorjian

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/Total Budget	Commitment (Person-Months per Year)
S. Kulkarni	ULTRASAT: Unveiling the Dynamic UV Sky	Astrophysics Explorer Mission of Opportunity/Science Mission Directorate/Dr. Wilton Sanders, (202) 358-0365, Wilton.T.Sanders@nasa.gov	6/1/2015 – 6/15/2023 $65M	5
V. Gorjian	SpEAR: Space Explorer for Accretion and Reverberation	Astrophysics Research and Analysis/Science Mission Directorate/ Dr. Michael Garcia/ 202-358-1053 / Michael.R.Garcia@nasa.gov.	**09 / 01 / 2015 - 07 / 31 / 2019**	2.8

5 Budget Justification

5.1 Budget Narrative

We are requesting sufficient funds to support the work effort required to process, analyze, and publish the results from the proposed program. We do have collaborators who will be working on this project as consultants that do not require funding.

5.1.1 Facilities and Equipment

Existing equipment will be sufficient for the successful completion of the requisite data staging, simulations, and analysis.

5.1.2 Rationale and Basis of Estimate

The "*Spitzer* Sources with Dusty Debris (S2D2): Finding The Most Unusual Infrared Excess Sources from the *Spitzer* Enhanced Imaging Products Archive" cost proposal was prepared using JPL's pricing/accounting system, which has been reviewed and approved by the DCAA. The rates applied in this proposal are JPL's current published rate set (version FY15-02), dated November 2014.

The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. The team provides the necessary relevant experience to develop a credible and realistic cost estimate. The cognizant individuals identify and define the products and the schedule needed to complete the tasks for each work element. The team developed the grassroots estimate using estimating methods and techniques (analogy, vendor quotes, historical experience) appropriate for each element of work. These methods are used to generate the detailed schedule and resource estimates for labor, procurements, travel, and other direct costs for each work element. The resource estimates are aggregated and priced using JPL's pricing/accounting system. JPL's process assures that lower level estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within their estimated cost.

5.2 Budget Details – Year 1

Direct Labor – Year 1

- Dr. Varoujan Gorjian is the PI and will oversee all aspects of the proposed work and will be in charge of doing the primary IR excess source selection. Dr. Gorjian's necessary time commitment in Year 1 amounts to 0.25 wy ($29.2K requested salary with $16.3K fringe benefits)
- Dr. Farisa Morales will serve as a Co-Investigator on this effort. Dr. Morales will aid in the vetting of the selected sources and the construction of the source catalog. Time Commitment is .25 wy. ($24.3K requested salary with $13.6K fringe benefits).

Other Direct Costs – Year 1

Subcontracts/Subawards

- Desktop Network Chargebacks (calculated at $6.67/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($6.3K)

Consultants

- There are no consultants required for this task.

Equipment

- There are no major equipment purchases necessary.

Services

- No additional services will be necessary.

Supplies and Publications

- Publication and Documentation: Miscellaneous publication and documentation charges ($2K).

Travel

- Travel for the AAS conference to present the initial results of the project ($2k)

Other

- Multiple Program Support (MPS) $10.6K.

Facilities and Administrative (F&A) Costs – Year 1

- Allocated Direct Costs (ADC) $28.5K.
- Applied General ADC $16.3K.

Other Applicable Costs – Year 1

- N/A

Total Estimated Costs for Year 1: $145,090.00

5.3 Budget Details – Year 2

Direct Labor – Year 2

- Dr. Varoujan Gorjian will continue to oversee all aspects of the proposed work and will be in charge of maintaining the catalog, overseeing the model fitting, and acquiring any extra data necessary to advance the modeling. Dr. Gorjian's necessary time commitment in Year 2 amounts to 0.25 wy ($30.7K requested salary with $16.9K fringe benefits)
- Dr. Farisa Morales will continue to serve as a Co-Investigator on this effort. Dr. Morales will apply her modeling code to determine attributes of the IR excess debris disks. Time Commitment is .25 wy. ($25.6K requested salary with $14.1K fringe benefits).

Other Direct Costs – Year 2

Subcontracts/Subawards

- Desktop Network Chargebacks (calculated at $6.67/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($6.3K)

Consultants

- There are no consultants required for this task.

Equipment

- There are no major equipment purchases necessary.

Services

- No additional services will be necessary.

Supplies and Publications

- Publication and Documentation: Miscellaneous publication and documentation charges ($2K).

Travel

- The PI will travel to the AAS meeting to present the final results ($2K)

Other

- Multiple Program Support (MPS) $10.6K.

Facilities and Administrative (F&A) Costs – Year 2

- Allocated Direct Costs (ADC) $28.4K.
- Applied General ADC $16.8K.

Other Applicable Costs – Year 2

- N/A.

Total Estimated Costs for Year 2: $149,450

Spitzer Sources with Dusty Debris (S2D2): Finding The Most Unusual Infrared Excess Sources from the Spitzer Enhanced Imaging Products Archive

ROSES ADAP

Timephased Cost Estimate Sheet

Dollars (Does not include Gov't Co-I's)

	Jan 2016 - Dec 2016		Jan 2017 - Dec 2017		Total Program		
Hours / (FTEs)							
(JPL PI)	471	(0.27 FTE)	474	(0.27 FTE)	945	(0.54 FTE)	Hours / (FTEs)
(JPL Co-I)	471	(0.27 FTE)	474	(0.27 FTE)	945	(0.54 FTE)	Hours / (FTEs)
Total Hours:	942	(0.54 FTE)	949	(0.54 FTE)	1,891	(1.08 FTE)	Subtotal
Amount		$53,490		$56,230		$109,720	JPL Direct Labor Cost w/o Fringe
Fringe		$29,940		$31,070		$61,010	Fringe
Category A		$0		$0		$0	Cat A Direct Labor Cost
Total Direct Compensation (includes Employee Benefits)		$83,430		$87,300		$170,730	Subtotal
Travel		$0		$0		$0	Direct Travel Cost
JPL Services		$0		$0		$0	Direct Services Cost
Procurements							
Chargebacks		$6,260		$6,320		$12,580	Direct Chargebacks cost
Subcontracts		$0		$0		$0	Direct PS cost
Procurement RSA		$0		$0		$0	Direct RSA cost
Purchase Orders		$0		$0		$0	Direct PM cost
Caltech Transfers		$0		$0		$0	Direct CT cost
Multi-Program Support		$10,640		$10,620		$21,260	Direct MPS cost
Total Direct Costs		**$100,330**		**$104,240**		**$204,570**	Subtotal
Allocated Direct Charge		$28,460		$28,440		$56,900	Total ADC
General & Admin		$16,300		$16,770		$33,070	Total G&A
Reserves (Burdened)		$0		$0		$0	
Total JPL Costs		**$145,090**		**$149,450**		**$294,540**	Subtotal
Government Co-I's Not in JPL's Costs		**$0**		**$0**		**$0**	Bypass
Total Costs		**$145,090**		**$149,450**		**$294,540**	Subtotal

CES_by_PY

JPL Cost Accumulation System

Introduction

All costs incurred at the Laboratory, including JPL applied burdens, are billed to the Government as direct charges at the rates in effect at the time the work is accomplished.

Allocated Direct Costs

Allocated Direct Cost (ADC) rates contain cost elements benefiting multiple work efforts, including Project Direct, MPS, and Support and Services activities. Rate applications for cost estimates are specific to the given category as stated below:

1) Engineering and Science (E&S)
2) Procurement: Purchase Order, Subcontract, Research Support Agreement (RSA)
3) General and Administrative (G&A): Basic, RSA
4) Specialized G&A applications: Remote Site

The accounting process fully distributes these costs to the respective project/task(s).

Multiple Program Support

The Multiple Program Support (MPS) rate applies costs for program management and technical infrastructure. Cost estimates and system application tools will apply the composite rate to all project direct hours charged to projects managed by JPL.

Employee Benefits

All costs of employee benefits are collected in a single intermediate cost pool, which is then redistributed to all cost objectives as a percentage of JPL labor costs, including both straight-time and overtime. Functions and activities covered by this rate include paid leave, vacations, and other benefits including retirement plans, group insurance plans, and tuition reimbursements.

For this proposal the estimated costs have been derived in the same manner as stated above. However, presentation of the estimated costs in the required tables has been adapted in the following ways:

1. The costs for Employee Benefits are included in the Direct Labor costs stated in this proposal.
2. Engineering and Science ADC and Procurement ADC along with MPS costs are displayed in the "Other" category in the Other Direct Costs section.
3. G&A is shown in the Facilities and Administrative Costs section.
4. JPL's forecasted labor rates equal an hourly laboratory-wide average for each job family and are further broken down by career level within the job family. Labor cost estimates apply the family average or family average career level rate to the estimated work hours. An actual individual's labor is considered discrete and confidential information and is only released on an exception basis and only if a statement of work identifies that specific individual as the only one able to perform a task. The use of family average or family average career level rates is consistent with the JPL CAS disclosure statement and the Cost Estimating Rates and Factors CDRL published in response to a requirement in NASA Prime Contract NNN12AA01C.

The proposed budget of the NRA proposal also covers labor costs for serving on NASA peer-review panels and advisory committee at the request of NASA discipline scientists or program managers.